

# **Design fires for tunnel water mist suppression systems.**

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## **ABSTRACT**

Water mist systems are unable to suppress or control large fires, therefore the 'design fire' for a water mist system in a tunnel should not be specified in terms of peak heat release rate, but rather in terms of the characteristics of a growing fire which such a system is designed to suppress. This paper reviews the growth rates of a number of fire experiments carried out in tunnels and makes observations regarding the influence of tunnel ventilation on these growth rates. Further experiments will be required to validate these observations. It is suggested that tunnel ventilation of the order of  $3\text{ms}^{-1}$  may provide the optimal conditions for rapid fire growth and that both higher and lower airflows may result in slower growing fires. Three 'design fires' for water mist systems are proposed.

**KEYWORDS:** Water mist systems, ventilation velocity, fire growth rates

## **INTRODUCTION**

There has been some debate regarding the issue of 'design fires' for tunnels in recent years. These design fires have been used for purposes such as estimating times to failure for structural elements and adequately dimensioning ventilation systems for smoke control. As a consequence of these emphases, discussion has focused more on the peak heat release rate (HRR) of a fire rather on the growth phase or any transient effects. Historically, design fires with peaks of between 20 and 50 MW have been commonly used for tunnels. However, experimental tunnel fires carried out in the past two decades have shown that peak HRRs between 100 and 200 MW may be more realistic. [1,2]

At present, there is a significant interest in water based suppression systems for tunnel environments. In Europe, particularly, the emphasis seems to be on water mist systems rather than traditional sprinkler systems. Water mist systems have been and are being installed in a number of tunnels in Austria and the tunnel sections of the new M30 Madrid ring road and the A86 near Paris. Other road tunnel operators are considering the use of such systems in their existing facilities.

Water mist systems, by their very nature, are unable to suppress large fires, thus they are only effective in the incipient stages of a fire involving a large vehicle. Therefore, the design fire for a water mist system for a tunnel should not be defined by the peak heat release rate which such a fire could attain, but rather by the characteristics of the growing fire which the system is designed to suppress or control. At present, the upper limit of fire size for operability of water mist systems has not yet been determined, but it is clear that it will be significantly lower than the possible peak HRR of a goods vehicle fire.

In order to adequately define a 'design fire' for vehicle tunnels is it therefore necessary to look at the growth characteristics of real fires in tunnels and define the 'design fire' on the basis of this.

## VEHICLE FIRES IN TUNNELS

Despite a significant amount of research into tunnel fire phenomena in recent years, the number of well instrumented, actual vehicle fire tests carried out in tunnels remains quite small. Indeed, to date, only one fire test of an actual heavy goods vehicle (HGV) has been carried out [3]. Other large scale fire tests have been carried out on solid fuel loads taken to be representative of HGV trailers or HGV cargoes [1,2,4], generally consisting of loads of wooden pallets, sometimes with additional plastic materials and coverings of various types.

The majority of experimental tunnel fire data that are available in the literature are from tests involving fuel pans and passenger cars. However, when designing a fixed fire suppression system for a tunnel, the scenario considered to be the 'design fire' by most parties involved is that of a HGV, not a pool fire or a passenger car.

Thus, in order to specify a realistic design fire for a water mist system (or other fire safety system), it becomes necessary to look at the data from tunnel fire experiments that are at least similar in fuel load and size to real HGV and their cargoes.

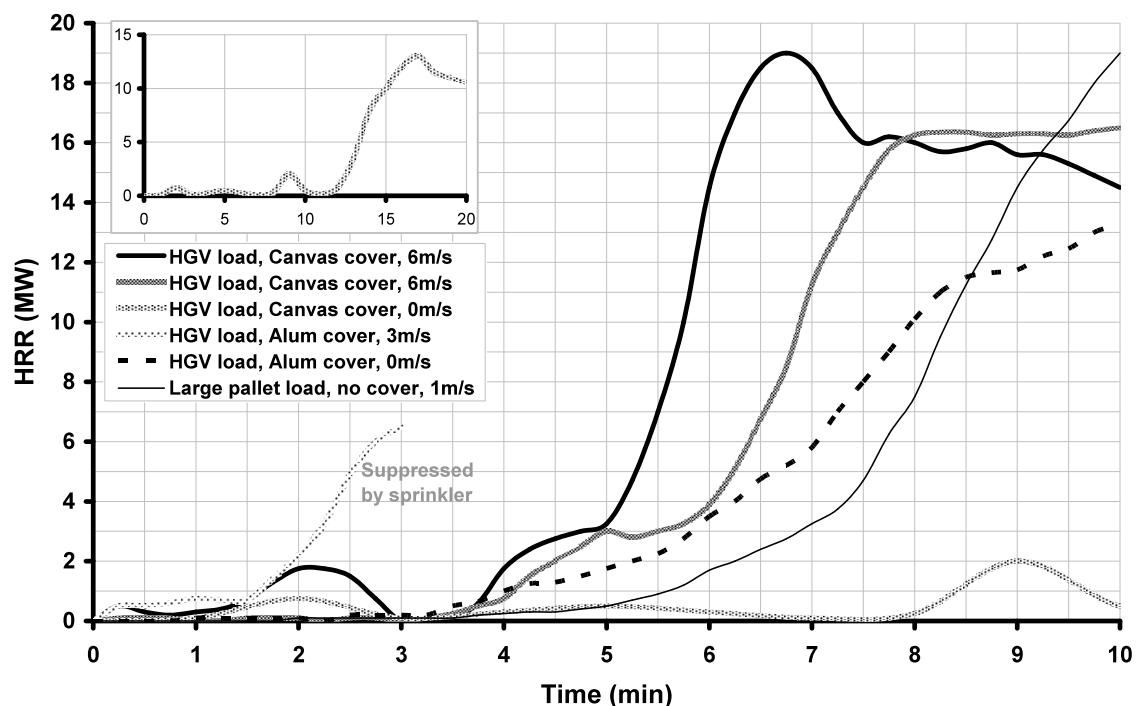


Figure 1 Fire tests in the 2<sup>nd</sup> Benelux Tunnel, 2002, HRR in the growth phase (approximate representation). The inset graph is the data for the HGV load with canvas cover and no longitudinal airflow, which did not grow significantly until about 12 minutes after ignition.

The following experiments may be taken to share characteristics with real HGV fires:

- HGV fire test, Hammerfest tunnel, 1992 [3]
- Simulated HGV truckload, Hammerfest tunnel, 1992 [5]
- Three HGV load tests with canvas cover, 2<sup>nd</sup> Benelux Tunnel, 2002 [4,6] (see Figure 1)
- Two HGV load tests with aluminium cover, 2<sup>nd</sup> Benelux Tunnel, 2002 [4,6] (see Figure 1)
- Large pallet load test (no cover), 2<sup>nd</sup> Benelux Tunnel, 2002 [4, 6] (see Figure 1)

- Four HGV trailer load tests, Runehamar Tunnel, 2003 [2] (see Figure 2)

These tests are discussed elsewhere and will not be described in detail here. Representations of the HRR data from the 2<sup>nd</sup> Benelux Tunnel tests and the Runehamar tests are shown in figures 1 and 2.

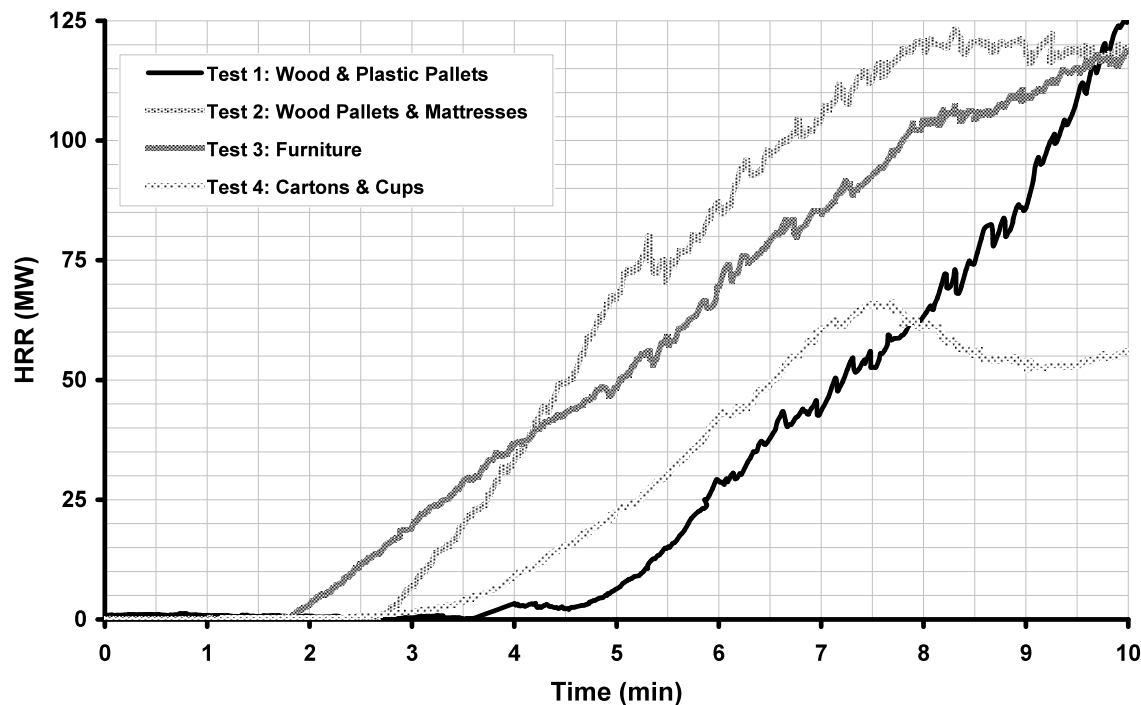


Figure 2 Fire tests in the Runehamar Tunnel, 2003, ignition and growth phase. The longitudinal ventilation in the tunnel was approximately  $2.5 \text{ ms}^{-1}$  for each of these tests during the growth phase. Thanks to Haukur Ingason & Anders Lönnemark [2] for the experimental data.

## OBSERVATIONS

Fires in compartments have often been modelled using a  $t^2$  fire [7], that is, the HRR of a fire is assumed to grow proportionally to the square of the time after ignition. Such fires are commonly classified as 'slow', 'medium', 'fast' or 'ultra fast' fires, with the constants of proportionality being approximately 3, 11, 44 and  $178 \text{ W s}^{-2}$  for these classifications.

None of the experiments listed above is adequately modelled using a  $t^2$  fire. In most instances the initial growth rate is similar to a 'medium' rate fire, but then there is a transition to a faster growth than an 'ultra-fast' fire. Indeed, rather than a parabolic relationship between HRR and time, all of these experiments would be better represented by a two-step linear approximation; the first step would be the slow growth from ignition to one or two MW in size, the second step would be the rapid growth from only a few MW to tens of MW.

Approximate representations of the data from the 2<sup>nd</sup> Benelux tunnel tests and the Runehamar tunnel tests, using this two-step approximation, are shown in Figure 3.

Two things may be observed when presenting the data in this manner:

1. There appears to be a correlation between the ventilation rate and the time between ignition and the onset of rapid growth, and
2. There may be a correlation between the ventilation rate and the rate of fire growth in the second step.

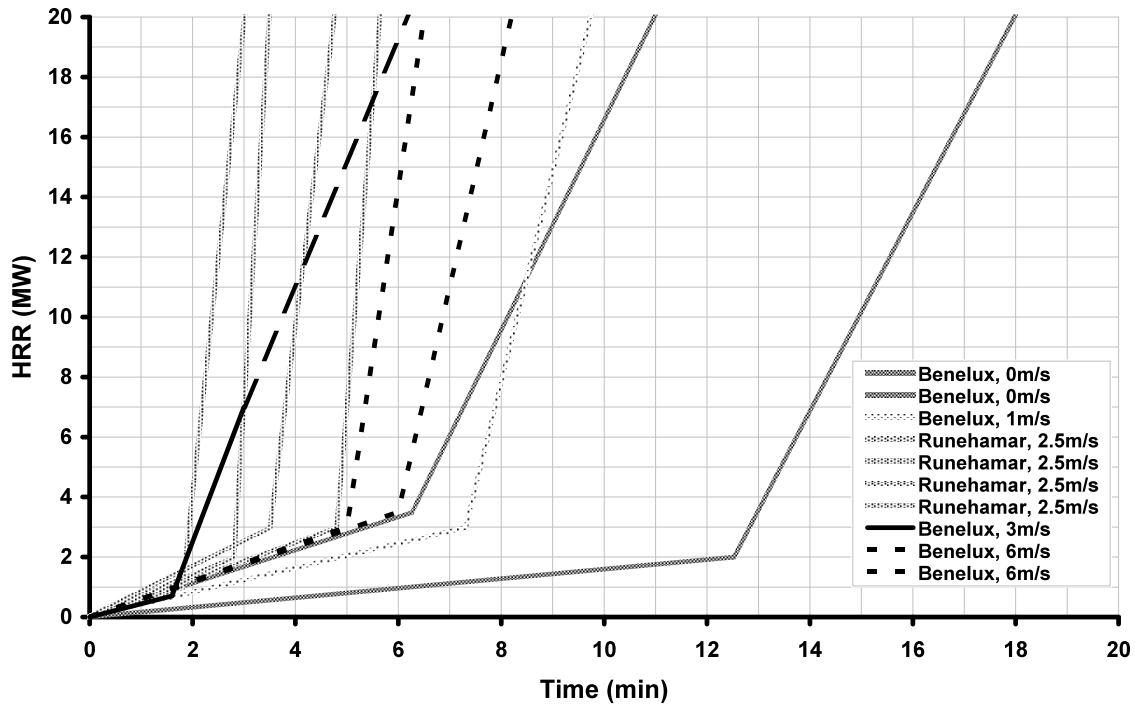


Figure 3 Two-step approximations of the HRR data from the 2<sup>nd</sup> Benelux Tunnel fire test series and the Runehammar fire tests.

Certainly, in the Benelux fire test series, those tests with no or low ( $1\text{ms}^{-1}$ ) forced ventilation have the longest delay between ignition and the onset of rapid growth; over six minutes. The two tests at high ventilation ( $6\text{ms}^{-1}$ ) had 'delay' times between five and six minutes, while the test with medium ventilation ( $3\text{ms}^{-1}$ ) had by far the shortest 'delay' time of less than two minutes. The four tests from the Runehammar tunnel, with airflow velocities of about 2 to  $2.5\text{ms}^{-1}$ , also fit the same pattern with delay times of less than five minutes.

Considering the gradients of the graphs also suggests that there is a similar correlation with fire growth rates; the tests with low ventilation rates have a smaller gradient than those with high ventilation rates. The Runehammar tests with medium ventilation rates have much steeper gradients than both the low and high ventilation tests, although this pattern is not borne out by the Benelux test with  $3\text{ms}^{-1}$  airflow. However, as that test was suppressed by a sprinkler 3 minutes after ignition, it is hard to make any judgement as to what the rate of growth might have been had it been allowed to burn.

These observations suggest that ventilation rates of the order of  $3\text{ms}^{-1}$ , might actually provide the optimal conditions for rapid fire growth, that is, the worst conditions for fire safety, whereas higher (or lower) ventilation rates might actually tend to delay the onset of rapid fire growth and reduce the rate of rise of this growth phase.

Unfortunately, for many years now, the results of smoke control studies [8,9,10] have proposed



ventilation rates of between 2.5 and 3ms<sup>-1</sup> as the *critical velocity* required to control smoke in tunnels and prevent *backlayering*. Obviously more research is required here, but if these observations are validated by future experimental testing, then the whole area of emergency ventilation response needs reassessed: which is worse, backlayering or rapid fire growth?

## DISCUSSION

With the exception of the 1992 HGV fire test, all the tunnel fire experiments described above involved only a representation of the trailer of a HGV. They therefore only model the scenario where the point of ignition of the fire is within the cargo of a HGV. In reality, the majority of HGV fires start in either the engine compartment of the tractor unit (overheating, fuel leak, etc.) or at the rear axle (brakes overheating). A real fire will therefore take some time, perhaps several minutes, to spread to the cargo. In the 1992 HGV fire test, the fire was started on the driver's seat and was confined to the cab for the first ten minutes.

Based on this observation it may be assumed that the initial 'delay' phase of the fire would be longer in reality than in many of the experimental tunnel fires presented here.

The delay times and gradients of the observed rapid growth phases of these experiments are summarised in Table 1, below.

Tunnel	Fuel	Ventilation	Delay phase	Growth phase
Hammerfest	HGV & Furniture	6 ms <sup>-1</sup>	12 minutes	60 MW/min
Hammerfest	Wood & Tyres	0.5 ms <sup>-1</sup>	Short	2 MW/min
Benelux	Wood, canvas	6 ms <sup>-1</sup>	5 minutes	11 MW/min
Benelux	Wood, canvas	6 ms <sup>-1</sup>	6 minutes	8 MW/min
Benelux	Wood, canvas	0 ms <sup>-1</sup>	12 minutes	3 MW/min
Benelux	Wood, aluminium	3 ms <sup>-1</sup>	2 minutes	6 MW/min
Benelux	Wood, aluminium	0 ms <sup>-1</sup>	6 minutes	4 MW/min
Benelux	Wood	1 ms <sup>-1</sup>	7 minutes	7 MW/min
Runehamar	Wood & plastic	~2.5 ms <sup>-1</sup>	5 minutes	20 MW/min
Runehamar	Wood & mattresses	~2.5 ms <sup>-1</sup>	3 minutes	26 MW/min
Runehamar	Furniture	~2.5 ms <sup>-1</sup>	2 minutes	14 MW/min
Runehamar	Plastic cups in boxes	~2.5 ms <sup>-1</sup>	4 minutes	16 MW/min

Table 1 Summary of experimental observations

The observations that can be made from such a limited pool of source data should not be considered in any way as authoritative, but may be of some use in defining design fires or in some other engineering calculations. The observed trends in the data are summarised in Table 2.

Ventilation rate	Delay phase	Growth rate
Low (less than 1ms <sup>-1</sup> )	6 minutes or longer	About 5 MW/min
Medium (about 3ms <sup>-1</sup> )	5 minutes or less	15 MW/min or more
High (about 6ms <sup>-1</sup> )	5 or 6 minutes	About 10 MW/min

Table 2 Summary of observed trends

In a real vehicle fire scenario it is likely that the fire will be subject to a number of different ventilation conditions. It is likely that the vehicle will be moving when the fire is in its initial stages, thus the airflow relative to the fire will probably be small in the 'upstream' direction (assuming that the dominant airflow is driven by the traffic flow). Once the fire is detected and the vehicle is stopped, the ventilation (still being driven by the traffic flow) will switch to a significant 'downstream' flow. Under normal ventilation control, the emergency ventilation will also operate in the 'downstream' direction, possibly greatly increasing the ventilation velocity. Unfortunately, if the observations above are correct, this scenario will probably result in conditions which will lead to a short 'delay' phase after the vehicle has stopped and a rapid linear growth rate. This is frequently observed in real tunnel fire incidents, witnesses report seeing a very rapid increase in fire size very soon after the vehicle is brought to a halt.

This may have consequences for recommended actions to be taken in the event of a fire in a tunnel. If stopping the vehicle may lead to a much faster fire growth rate, might it be better to continue to the portal (assuming this is not many kilometres away) or a designated fire point rather than stopping when the fire is first discovered? Of course, this depends on many factors, requires more research and is outwith the scope of this discussion.

But these observations do have consequences for design fires for suppression systems.

## TOWARDS A DESIGN FIRE

When defining a design fire, the times for detection, fire growth and system activation must be carefully considered. It is vital to have a clear understanding of the capabilities of the *detection* system and the lead-in times for activation of the emergency ventilation and suppression systems. In many cases, the delay between detection and activation may be a few minutes. If this is the case, it is essential that the detection system is capable of detecting a small fire (perhaps of the order of 1 MW) during the 'delay phase'. If this is not achieved and the fire is not detected until it enters its rapid growth phase, the resulting fire will, in all likelihood, be well beyond the capabilities of a water mist system once it is activated.

Thus, the assessment of performance of a water mist system is entirely coupled with the performance of the detection system. This means that the required detail in the performance assessment of the detection system has to be comparable to that of the water mist system.

On the basis of the observations above, when defining a design fire it is also necessary to take account of the likely ventilation conditions that a real fire in the tunnel will experience.

Three example scenarios are presented which may be used to define a design fire:

1. The ventilation is initially low and remains unchanged, leading to a delay phase of about six minutes and a low growth rate of 5 MW/min.
2. The traffic-induced airflow, about  $3\text{ms}^{-1}$ , remains unchanged, leading to a delay phase of only three minutes followed by a high linear growth rate of 15 MW/min.
3. An emergency ventilation of  $6\text{ms}^{-1}$  is activated quickly, extending the delay to five minutes and slowing the growth rate to about 10 MW/min.

These scenarios are shown in Figure 4. For example purposes, we assume here that the detection system is unable to detect the fire within the first two minutes of growth and that there is a four minute delay between detection and full system activation. These two times are indicated using dotted

lines.

Of these three scenarios, the largest fire at the point of activation of the suppression system would be a 30 MW fire growing at a rate of 15 MW per minute. If the emergency ventilation could be activated very swiftly, the scenario might be more like a 12 MW fire growing at a rate of 10 MW per minute. Of course, if the time lag between detection and activation is more than four minutes, then the fire growing at 15 MW/min could be significantly larger than any water mist system is capable of suppressing.

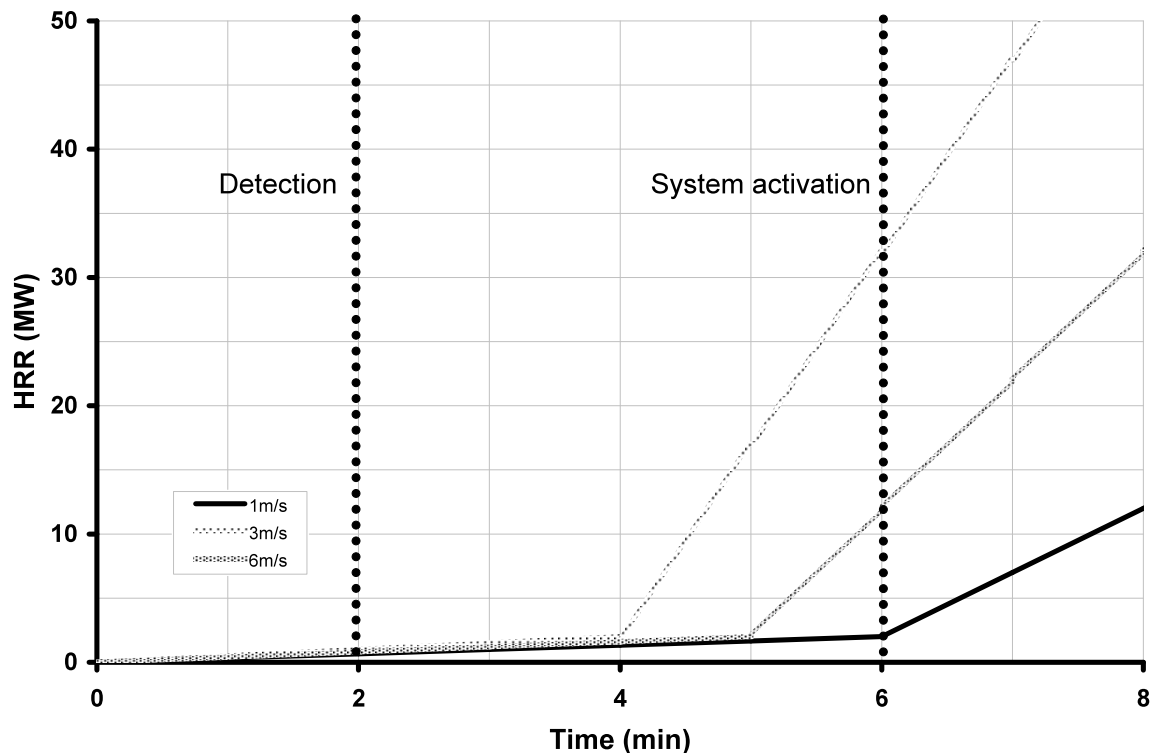


Figure 4 Example design fire scenarios

The third case of a 2 MW fire growing slowly is trivial. However, it should be noted that this case is similar to a number of fire experiments which have already been carried out to test or demonstrate water mist systems for tunnel applications (although the majority of such tests have been carried out with liquid fuel pool fires, which respond in a different manner to the influence of longitudinal ventilation).

## CONCLUSIONS

- It has been observed that there is an apparent relationship between the rate of growth of a solid fuel fire in a tunnel and the tunnel ventilation velocity.
- It may be that the fastest fire growth occurs at about  $3\text{ m s}^{-1}$  airflow velocities, leading to 'worst case' fire scenarios.
- Both higher and lower ventilation rates may result in slower growing fires.
- Tunnel fires are not adequately modelled using a  $t^2$  fire curve, a two-step linear curve gives a more accurate representation.
- Design fires for water mist systems should be based on the characteristics of a growing fire and

should take into account the time delay between detection and system activation.

- These observations are made on the basis of only a few experiments. More research is needed to confirm (or otherwise) the validity of these conclusions.

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